

NATIONAL BUREAU OF STANDARDS REPORT

6662

SYNTACTIC TECHNIQUES IN INFORMATION RETRIEVAL

A report from the Research Information Center and
Advisory Service on Information Processing
Data Processing Systems Division

To the

National Science Foundation

January 13, 1960



**U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS**

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1205-12-12456

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SYNTACTIC TECHNIQUES IN INFORMATION RETRIEVAL

I. INTRODUCTION

In this discussion we are ultimately concerned with the problem of developing a fully mechanized information selection and retrieval system. For the immediate purposes of this report, however, we will be concerned with only a part of the problem -- namely, outlining those parts of the information selection and retrieval problem which may profitably be investigated from the point of view of certain techniques in structural linguistics.

The problems to be discussed here may not be new to the worker in the field of mechanized information retrieval, nor, for that matter, may many of the syntactic considerations that will be brought up. ¹ (Many of these points are mentioned in varying detail in Chomsky's Syntactic Structures.) What is suggested as novel is the thesis that problems which are or may be important linguistically are also important to one attempting to develop a mechanized information selection and retrieval system insofar as solutions to the syntactic problems will considerably advance a solution to the mechanized information retrieval problem.

We are less concerned here with proposing solutions to the syntactic problems mentioned than we are with stating the problems and with outlining a point of view (in some cases different from that which the structural linguist might otherwise adopt) which can orient these investigations in such a direction as to contribute more directly to the solution to the information selection and retrieval problem.

II. THE INFORMATION SELECTION AND RETRIEVAL PROBLEM

Let us first adopt an operational definition of what constitutes a fully mechanized information selection and retrieval system which is sufficient for our present purposes. Let us consider a system which requires no human intervention and which can locate information in a large technical library with a quality of performance and a speed which have as lower bounds the peaks achieved by a good research librarian. When we speak of a good research librarian we include the technical researcher himself who brings to bear on the retrieval operation his own special viewpoint as an expert in the field of investigation. There is a host of problems involved in creating such a "mechanized librarian", in maintaining the performance of

the system in the face of changing requirements, and in operating the system to provide the retrieval product to the customer. From among these many problems we single out three for consideration in this paper:

- a. Mechanized analysis of documents in written natural language (English)
- b. Mechanized analysis of questions, i.e., search prescriptions, which also appear in natural language
- c. Determination of the Question Answering Relevance (QAR) with respect to the search prescription of an information item located in the collection.

A. Analysis of Natural Language Documents

Among information retrieval workers most proposals for analyzing documents are of such a nature that they can be implemented only by human beings. Wherever any type of mechanized analysis has been considered, the type of end-product aimed for has been much too limited in its use to be of interest to us here; thus, in Luhn's² "auto abstracting" approach a statistical analysis of word frequencies enables a machine automatically to extract sentences from a document in such a way that the sentences extracted presumably convey the main information of this document. Even if this could be done, consistently, it would by no means allow any depth of analysis of the internal structure of sentences and of their interrelationships. This approach can at best lead to a screening technique which must then be followed by an analysis in depth of the internal structure of the material being analyzed.

Of the non-mechanized approaches that have been considered, that of Newman³ at the U. S. Patent Office typifies those which use some intermediate "ruly" language for encoding documents: The presumption is that some regularized synthetic language can more accurately convey meaning (particularly within a mechanized system) than can a natural language. Here we take the contrasting point of view, along with Yngve⁴, that English represents a highly regular language, very well "engineered" for the purpose of conveying meaning within an information retrieval system. What is lacking, of course, is our proper and complete understanding of the structural rules governing the operation of the language.

We might also mention the approach of Williams⁵ & 5a at Itek Corporation, which seems to be an attempt to use whatever syntactic information about English that we have available to regularize natural language documents, but only to the extent that unwanted information is eliminated (or that implicitly-conveyed information is added or is more

expressly defined). This approach coincides with ours as far as it goes. We are, however, ultimately concerned with making automatic analysis of English documents in such a way that the intended meaning of the message is preserved or conserved. Needless to say, to accomplish this more ambitious objective, we must confront many difficult syntactic problems. Some of these problems are discussed later in Section III.

B. Analysis of Natural Language Questions

Although the problems involved in the mechanical analysis of search prescriptions formulated in English to an information selection and retrieval system are largely parallel to those of analyzing documents that are written in natural language, we have singled out the problem of question analysis largely because methodologically it seems to be a more tractable problem to attack first. The reasons for this relative tractability derive mostly from the fact that we may consider the problem of furnishing questions to a machine to be that of a two-way communication system in which a question is furnished to the machine and in which the machine may subsequently ask for further elucidation of the meaning of the question. Thus we might conceive of a mechanized system in which when a question is furnished to the machine it responds by asking for a definition of some term or the reformulation of the originally given syntactic structure along the lines of a prototype suggested by the machine.

C. Determination of the Question Answering Relevance of Information Items

This is the most difficult of the three problems considered here. A common, very straightforward, and correspondingly useless method for mechanizing the evaluation of information items with respect to their QAR is to perform a word-for-word matching of the question (or sometimes just the nominal constructions in the question) against similar parts of the item being evaluated. Thus a question inquiring about "methods (for the) production (of) starch" commonly retrieves not only information items such as "methods (used in the) production (of) starch" but also "methods (of using) starch (in the) production (of adhesives)".

The main reasons why the QAR problem is so difficult is that it requires an investigation of the relationship between the syntactic clues in a sentence and what has been called the "*semantic freight*" carried by the sentence.

Now that we have stated our concern with linguistic problems and their relation to the information selection and retrieval problem, we may consider those problems of a syntactic nature which we must confront if we are to achieve the goals mentioned above.

III. SYNTACTIC PROBLEMS

A. Development of a Grammar

It is quite evident that if we are to handle natural linguistic phenomena in a mechanized system we must have explicitly, or otherwise, the ability to build into the system a grammar of the natural language. Interestingly enough, many approaches to mechanizing information selection and retrieval have implicitly confronted the grammar problem by the use of a terminology in which the machine representation of concepts explicitly provides the grammar of the language. Thus, where it is necessary to state that a particular relationship exists between two terms, the machine code for these terms indicates the presence of that relationship. This rather naive approach has been necessary when the mechanization used consisted of nothing more sophisticated than punched card machines.

However, with the availability of the stored-program digital computer, we can consider the much more natural approach that characterizes all real languages in which the representation of words bears only slight relation to the grammar that governs their operation. This allows us to proceed to develop a grammar without the necessity of concerning ourselves with such problems as, for example, the efficient use of memory storage capacity. In the following sections we consider some of the problems involved in devising a natural language grammar of (say) English for use in information selection and retrieval systems.

1. The question of grammar models

Although Chomsky⁶ concentrates on three possible models for representing natural languages, we may give passing mention here to a total of seven distinct models from which we must select in designing a grammar. The first two correspond to Chomsky's finite state and phrase structure models. The third, which should be emphasized as being fundamentally more powerful than either of the former, is the phrase structure language with context dependency rules. From a theoretical standpoint, it might not be worthwhile to distinguish the number of symbols allowable in context dependency substitution rules. From the machine standpoint, however, it may turn out that rules which allow inspection of the adjacent $N + 1$ symbols are essentially more powerful than those which allow inspection only of N adjacent symbols. This gives us a whole continuum of phrase structure grammars with context dependency substitution rules.

The fourth model, developed by Solomonoff ^{7 & 7a}, is that of the multi-level phrase structure grammar. In such a grammar the first level rules are the contentional phrase structure rules; at the second level are production rules which form new first level substitution rules; third and higher levels are possible. This model is particularly attractive insofar as Solomonoff has developed techniques for discovering multi-level phrase structure grammars.

The fifth and sixth models are, respectively, transformation grammars with and without decision procedures. These transformational grammars may possibly be equivalent to suitable multi-level phrase structure grammars. The latter have the important advantage that we know something about their discovery procedures. The seventh model is that of the universal Post system which is, of course, unnecessarily powerful for our purposes.

Although Chomsky has given persuasive arguments why language is essentially transformational in nature, we suggest here that considerations of machine economics might require us to use one of the three-phrase structure models for a machine grammar. We must keep in mind that what leads to a neat, tight linguistic theory need not necessarily lead to economical machine implementation.

2. Semantic considerations

Chomsky¹ quite correctly points out that semantic considerations cannot form the basis for a grammatical description of English. He also points out conversely that a grammar may offer considerable insight into the study of meaning. What he fails to point out, and what is essential for our purposes, is that semantic considerations may form the basis for a choice among alternative grammars. When the linguist has the opportunity to describe a phenomena in various distinct ways, commonly he chooses that way which offers the most economical description of the largest number of phenomena. However, when we attempt to build an information retrieval grammar, we must try to devise rules which have demonstrated effect on the meaning of the sentences involved from the standpoint of the information selection and retrieval operations to be performed.

In a transformational grammar, for example, we want certain transformations which are meaning-preserving and others which when they operate have a consistent effect on the meanings of the sentences that they transform. Even so simple a transformation as the passive transformation fails to meet this requirement unless suitably modified, since such sentence pairs as "everybody loves somebody" and "somebody is loved by everybody" are clearly not

equivalent in meaning. This particular problem can very likely be solved within a transformational grammar by allowing the introduction of quantifier expressions like "some", "each", "every", "all", etc., only after the passive transformation.

3. Recognition techniques

Evidently a grammar for use in an information selection and retrieval system must in some sense be a decidable grammar. That is, it must be possible when given a purported sentence, to produce, if it exists, the derivation of that sentence within that grammar. Most probably any grammar that is sufficiently powerful to describe widely diverse linguistic phenomena will be in the logical sense undecidable. It is important to recognize just what is meant by the undecidability of a grammar. We can consider an undecidable grammar to be one for which there exists at least one sentence of which it cannot be effectively asserted by (say) a Turing machine whether that sentence belongs to the set of grammatical or ungrammatical strings. Let us suppose, then, that we have such an undecidable grammar. Is this grammar of any use from the machine standpoint? Generally speaking, even an undecidable grammar can be quite useful because the undecidable sentences might be sufficiently uncommon that they never occur in practice.

Although we must accept the theoretical importance of the general unsolvability of the recognition problem, we should simultaneously realize that this need not impede practical developments. There is always the likelihood that heuristic analysis techniques such as those used by Newell and Simon 8 & 8b for the incidentally, decidable, propositional calculus may provide us with the techniques necessary for analyzing the decidable sentences of an undecidable grammar. In fact, if it could be established that English is intrinsically undecidable, this would even more strongly indicate that speakers of the language who can, of course, analyze some sentences are using precisely the heuristic techniques which we would like to discover 9 & 9b. Similarly, it might well be indicated that machine decision procedures can be defined which will fail to analyze correctly those sentences, but only those, that are intrinsically undecidable for the human analyst.

4. Handling ambiguous sentences

If we have a grammar and recognition techniques for that grammar, we may wonder how to handle sentences with non-unique derivations. The most obvious mechanism is to assign probabilities to various sentences where the probabilities are determined by such considerations as the length of derivations. Then for retrieval purposes, sentences are used with probabilities determined by the probabilities of their derivations. There is no need, however, to introduce a probabilistic element into our recognition procedures. We may simply require that analysis of any sentence proceed in a certain order or sequence. The first or earliest complete analyses produced are the ones to be accepted. The later analyses are used only if earlier ones are inadequate for some reason.

This type of ordering procedure is an inevitable by-product of any mechanized sequential recognition procedure, because, for example, a computer in analyzing sentences will produce the analyses in some very definite predetermined order. What is suggested here is that ordering can be made significant and can perhaps correspond to the ordering used by a person hearing the language. Further evidence for this natural ordering of sentence analyses comes from the fact that a very large fraction of the sentences encountered in ordinary technical prose, which are usually considered to be unambiguous, can upon close inspection be seen to have many ambiguous derivations. This observation is well known, for example, to examiners in the U.S. Patent Office where the ambiguity of a sentence can significantly affect its legal status and consequently patent applications are very carefully inspected with precisely this consideration in mind.

5. Handling units larger than sentences

The transformational grammars which have been discussed in the literature have phrase structure counterparts which typically begin with a single symbol, S, representing the sentence as the main unit of concern. We wish to suggest that for information selection and retrieval purposes we must first of all adopt as our main unit of concern sequences of sentences rather than individual sentences. It may also turn out to be more economical from the machine standpoint to replace the single S with a set of symbols representing different kinds of sentences, that is, sentences which have different information retrieval status. From the theoretical standpoint this is unnecessary, as

Chomsky has shown, but from the practical standpoint replacing (S) by (DS, QS, IS, ...), corresponding to declarative sentence, question sentence, imperative sentence, ..., may make it easier for a machine to distinguish the different courses of action that are to be taken in an information selection and retrieval operation when the machine is confronted with a given sentence.

Another major problem in handling larger-than-sentence units is the problem of antecedents. In connected technical prose we must be able to detect antecedents of pro-elements where the antecedent will generally cross sentence boundaries. It is unlikely that any automatic analysis procedure can be successful without first solving this problem.

6. Development of grammar debugging procedures

There is a striking parallel between writing a grammar and writing a computer program. Both of these tasks are, in the limit, theoretically undecidable in that there exists no uniform procedure for determining when one has done the job properly. However, computer programmers are not, and linguists need not be, concerned over this theoretical limitation. The programmer has developed fairly sophisticated debugging procedures which allow him in almost all cases of practical interest to arrive at a correctly written program. The techniques for this accomplishment start as an art and eventually become a science. We suggest that the linguist may do similarly. The COMIT program of Yngve¹⁰ is a good step in this direction. Ultimately, we may hope for sophisticated automatic diagnostic techniques which may test a grammar in very much the way that post-mortem analysis programs aid in computer programming debugging.

B. Experimental Use of a Grammar

Let us assume in this section that the problems in developing a grammar which have been discussed above and many other difficult problems have been sufficiently solved to provide us an efficient, reasonably decidable set of recognition procedures for English text. We wish to inquire into some of the experimental investigations that may be attempted through the use of such a tool. We are thus not necessarily presuming that the solution to the recognition problem is in itself sufficient to enable us to perform selection and retrieval operations on English text. The grammar may be looked at as a necessary preliminary to certain crucial experimental investigations.

1. Test of Harris's conjecture

Harris¹¹ has asserted that the main information-bearing elements of a sentence can be made sufficiently explicit for retrieval purposes by obtaining the kernel of the transformed sentence. By matching the kernel (or what Harris calls the "center" of the kernel) with that of the question, he believes that the QAR problem can be solved at least in part. This is certainly true, and the important question is to determine just how much of a solution to the general problem this provides. We can see no other way of determining this than by experimentally investigating how well our recognition grammar enables us to match questions with test items, i. e., by empirical investigation.

2. Use of special-purpose clues

The sense in which we have described the grammar above precludes the incorporation within the grammar of special-purpose devices which are only of parochial interest within a particular subject matter speciality. We must not overlook, however, the possibility that in many cases the use of these rather ad hoc special-purpose devices may mean the difference between successful and unsuccessful information retrieval. As an example of such special-purpose devices we might consider the peculiar legal status of models in Patent Office retrieval. Thus the sentences, "I build a device", "I can build a device", "I shall build a device", and "I would build a device", have significantly different meanings to the examiner.

A more common example is the use of the special terminology. Within any subject matter area, technical terms often have peculiar syntactic behaviors. We would propose to make explicit such behavior, but as special-purpose devices rather than within the central grammar. Ray and Kirsch¹² have pointed out in a different context that this has the outstanding advantage of allowing us to use a widely applicable general-purpose grammar and to call in special-purpose clues according to the dictates of the particular subject matter being searched.

3. Making primitive logical deductions

We could not conceive of a very sophisticated information system that did not have the ability to make elementary logical deductions from linguistic cues. Unfortunately, however, the problem of rendering explicit the connection between linguistic and logical usage has not received any satisfactory solution after many years of concern by logicians. We can only indicate here our hope that availability of a machine grammar as an experimental tool may suggest new avenues of approach to this old problem.

A more promising approach, though more conservative in its goal, is the use of list processing computer programs of the type being investigated, for example, by Minsky and McCarthy¹³. We may expect to use such techniques for furnishing to the machine definitions of special terminology to be used by the machine in interpreting English sentences. In particular, when it is necessary to provide recursive definitions of terminology, the list processing techniques may prove especially attractive.

An interesting logical problem which might be solvable through syntactic clues is the problem of detecting what we may call "switching of metasearch levels". To understand this phenomenon, consider the following six questions as examples of six distinct metasearch levels which occur fairly commonly as search prescriptions to an information selection and retrieval system:

- a. What is the boiling point of water?
- b. What document gives the boiling point of water?
- c. How many documents give the boiling point of water?
- d. In what classification category can information on the boiling point of water be found?
- e. How much would it cost to perform a search for information on the boiling point of water?
- f. When would it be cheapest to run a search for information on the boiling point of water?

The machine's response to the first question should be to supply a piece of information; to the second, to supply a document name; to the third, to give a number (of documents); to the fourth, to give a category name; to the fifth, to give a price; and to the sixth, to give a time. It is deceptively easy for a customer to furnish any one of these questions to a machine. Yet, unless advance provision is made in the question analysis grammar it will not generally be possible for the machine to determine that a basically different type of action is called for in each case. Bar-Hillel¹⁴ has made a point of distinguishing the first two question types. We would prefer to be able to distinguish at least all six question types. It may be possible to use syntactic clues to solve this problem.

4. Providing for two-way communication

We can imagine a situation in which a question furnished to the machine might have a particular syntactic structure that the machine cannot, for one reason or another, resolve unambiguously. The same situation will occur more frequently when the machine is analyzing documents. Since the question represents a more crucial part of the total search operation than does any one documentary item, we should like to have a means to remedy this situation when it occurs in the search prescription. The simplest artifice for accomplishing this appears to be to allow the machine to ask for partial reformulation of the question.

Of course, most desirable of all would be asking the customer to give a grammatical analysis of his question. Since we presume no knowledge of the machine's grammar by the customer, this is not possible. Instead, we may allow the machine to gently guide the customer to an unambiguous question formulation by letting the machine suggest prototype search prescriptions to the customer which are based on the originally formulated question. By a series of successive approximations, this can lead to an unambiguous question.

IV. CONCLUSION

Our main concern in this paper has been to explore possible areas where the linguist who is concerned with formal techniques for the analysis of written language can contribute to the design of a very ambitiously conceived information selection and retrieval system. We have not presumed to offer any solutions to most of the problems mentioned here; rather, we mean to imply that these are important practical problems. We hope that they are also interesting ones.

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